International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

2010 - Fifth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

27 May 2010, 4:30 pm - 6:20 pm

Static and Dynamic Behavior of Earthen Slopes in the Region of Uttarkashi, India

Govardhan Bhat
IIT Roorkee, India

Navjeev Saxena
CBRI, CSIR-INDIA, India

S. K. Prasad
S.J. College of Engineering, India

Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

STATIC AND DYNAMIC BEHAVIOR OF EARTHEN SLOPES IN THE REGION OF UTTARKASHI, INDIA

Govardhan Bhat
Research Scholar
EQ. Engg. Deptt. IIT Roorkee
Roorkee, Uttrakhand, India

Dr. Navjeev Saxena
Scientist
CBRI, CSIR-INDIA
Roorkee, Uttrakhand, India

Dr Prasad, SK
Asstt. Professor
S.J. College of Engineering
Mysore, Karnataka, India

ABSTRACT

Earthen slopes experience considerable degradation in strength and stiffness during seismic activities. Past earthquakes have revealed the development of landslide and permanent movement of earth mass towards downstream. In this paper, a finite element analysis using GEOSLOPE on earthen slopes under static and dynamic loading due to earthquake has been carried out. The earthen slope is idealized as a plane strain two-dimensional model and base acceleration in the form of typical earthquake motion is represented as external loading. The performance of the slope including the stresses and displacements are analyzed. Further, the focus is on the determination of permanent displacement using Newmark's sliding block model including parametric studies for both static and dynamic cases.

INTRODUCTION

Slopes may be artificial that is manmade as in cuttings and embankments for roadways railways, earthen dams, levees and river training works, landscaping operations for development of sites etc. slopes may also be natural as in hill side and valleys coastal and river cliffs and so on. In the above cases forces exists which tend to cause the soil to move from high points to low points,. The downward and outward movement of the entire mass of soil causes failure or instability. The failures of slopes occur mainly due to (1) the action of gravitation forces and (2) seepage forces within the soil.

In areas of seismic activity, earthquake motions can induce significant inertia forces in a slope. These forces are also an important factor causing instability. The forces causing instability (called the actuating forces) induce shearing stresses throughout the soil mass. The induced inertial forces will also alternate in direction and magnitude numerous times, only those inertial forces that exceed the failure limit of the slope will induce further displacement.

The possibility of the occurrence of a failure where a slope is subjected to earthquake loading depends on viz; geometry, geology of the slope, soil engineering properties, ground water regime, presence of pre-existing shear zones and weather etc.

Methods of Analysis

Slopes become unstable when the shear stresses on a potential failure surface exceed the shearing resistance of the soil. In the case of slopes where stresses on the potential failure surface are high the additional earthquake induced stresses needed to trigger failure are low. In this sense the seismic slope stability is dependent on the static slope stability. The most commonly used methods of slope stability analysis are the limit equilibrium methods. Stress-deformation analyses, using the finite element method, are performed more rarely, especially in the case of major projects.

Limit-equilibrium methods.

The limit equilibrium methods have been used extensively for many years for the analysis of natural and manmade slopes. They have been calibrated against actual slope failures and with careful selection of appropriate input parameters these methods can yield sufficiently accurate results. With these methods the force or moment equilibrium of a mass of soil above a potential failure surface is considered. Shearing is assumed to take place on the potential failure surface with the soil above assumed rigid. The soil on the potential failure surface is assumed rigid-perfectly plastic and its shear strength is mobilized concurrently on all points on the failure surface. Since the states of stress and mobilized strength are the same for all elements of soil on the failure surface, the factor of safety is constant over the entire failure surface. In real slopes however the factor of safety for each element of soil on the failure surface is not constant. A number of limit equilibrium procedures have been developed and applied in practice.

Some of these procedures are listed below together with the type of slope failure and these are most applicable for-
Culman method (plane failures)
Wedge methods (failure on two or three planes)
Fellenius method (circular and log spiral failures-homogeneous soils)
Bishop´s simplified and Bishops modified (circular and log spiral failures-homogeneous soils).

Stress-deformation analyses.

Stress-deformation analyses can be performed mainly with finite element models, which allow the simulation of the complicated stress-strain behavior of soils. The finite element method is powerful tool, which can cope with irregular geometries, complex boundary conditions and pore water pressure regimes and can simulate complicated construction operations. The method can predict stresses, movements and pore water pressures due to construction procedures and also predict the most critically stressed zones within a slope. In this way the most likely mode of failure can be identified and deformations up to and sometimes beyond the point of failure can be calculated.

SEISMIC SLOPE STABILITY

Seismic slope stability analyses are further complicated by two additional factors (i) dynamic stresses induced by earthquake shaking and (ii) effect of dynamic stresses on the stress stains behavior and strength of slope materials. Depending on the behavior of the soil during seismic shaking, seismic instabilities may be grouped into two categories: (i) inertial instabilities and (ii) weakening instabilities

In the case of inertial instabilities the strength of the soil remains relatively unaffected by the earthquake shaking and any permanent deformations are produced when the strength of the soil is exceeded during small intervals of time by the dynamic stresses. In the case of weakening instabilities the earthquake shaking produces a substantial loss of strength, which gives rise to very large displacements and instability. The most common causes of weakening instability are flow liquefaction and cyclic mobility. There are numerous analytical techniques that deal with the above two categories and these are either based on limit equilibrium or stress-deformation analyses.

Analysis of Inertial Instability

When the dynamic normal and shear stresses on a potential failure surface are superimposed upon the corresponding static stresses, these may produce inertial instability of the slope if the shear stresses exceed the shear strength of the soil. The problem is approached either by performing a pseudo static analysis that produces a factor of safety against slope failure or by attempting to calculate permanent slope displacements produced by earthquake shaking.

Pseudo static Analysis.

The pseudo static approach has been used by engineers to analyze the seismic stability of earth structures since the 1920´s. This method of analysis involves the computation of the minimum factor of safety against sliding by including in the analysis static horizontal and vertical forces of some magnitude.

Permanent deformation analyses.

Newmark [1965] first proposed the important concept that the effects of earthquakes on embankment stability should be assessed in terms of the deformations they produced rather than the minimum factor of safety. He presented a method of analysis based on this concept in his Rankine Lecture in 1965. The method assumes rigid-plastic materials and presumes knowledge of the time history of the acceleration acting on the embankment during the earthquake.

Makdisi-Seed analysis.

The method proposed by Makdisi and Seed [1978] for calculating permanent slope deformation of earth dams produced by earthquake shaking is based on the sliding block method but uses average accelerations

Stress-Deformation analysis.

Stress deformation analyses are usually carried out using dynamic finite element programs. The permanent deformations of a slope are produced by integrating the seismically induced permanent strains in each finite element. Various methods have been used for calculating permanent strain within individual finite elements namely:

(i) The strain potential approach.
(ii) Stiffness reduction approach.
(iii) Non-linear analysis approach.

Analysis of Weakening Instability

Weakening instability occurs when the earthquake induced stresses and strains result in a substantial reduction of shear strength. They are usually associated with the phenomenon of liquefaction and they fall into two main categories.

(i) flow failures
(ii) Deformation failures.

Flow failures.

Flow failures occur when, due to earthquake shaking the shear strength of the soil drops below the soil strength required to maintain static equilibrium. These failures may occur under static conditions after the earthquake shaking was ceased and they usually produce very large deformations which take place very suddenly and without warning. They can cause tremendous amount of damage and loss of life. A number of empirical, semi-empirical and analytical methods have been used for analyzing weakening instabilities.

Deformation failures.

Deformation failures are usually smaller in magnitude than flow failures and they occur when the shear strength of the soil is reduced by earthquake shaking to such an extent that this is temporarily exceeded by pulses of earthquake-induced shear stresses. By studying actual permanent earthquake induced ground displacements in uniform sands of medium grain size Hamuda et. al. [1986] proposed an empirical relationship for calculating permanent horizontal down slope ground displacement

$$D = 0.75\, H^{1/2}\, i^{\,1/3} \qquad (1)$$

Where,
D is ground displacement in meters
H is thickness of liquefied layer in meters and
i is the largest of the ground slope and the slope of the lower boundary of the liquefied layer (%)

Youd and Perkins [1987] proposed the Liquefaction Severity Index (LSI) for a conservative estimate of ground displacements related to lateral spreads on wide flood plains, deltas or other gently sloping fluvial deposits.

Using a model of a slope consisting of a crust of intact soil resting on a layer of liquefied soil and by employing work energy principles Byrne [1991] proposed expressions for calculating permanent slope displacements. Byrne et. al. [1992] extended his approach to calculate stiffness reduction factors for use in finite element analyses. The failure of the upper San Fernando dam was modeled using this approach and the deformations predicted were in good agreement with the actual deformations.

FINITE ELEMENT ANALYSIS

Finite element analyses have been carried out approximating the problem as plane strain. The dynamic boundary conditions are arrived through iteratively changing the boundary to represent the unbounded soil media. It follows the convergence study Govardhan [2007].

Plane Strain Analysis using Finite Element Method

The finite element concepts to a real geotechnical problem requires certain assumptions and idealizations. In particular, it is necessary to specify soil behavior in the form of a mathematical constitutive relationship. Due to the special geometric characteristics of a long slope, additional simplifications of considerable magnitude can be applied. The force and or applied displacement boundary conditions are perpendicular to, and independent of, this large dimension, all cross sections can be assumed the same. Therefore, all major forces act in a plane of cross section (x-y plane) causing major deformations to occur in x-y plane and hence modeled as plane strain problem. GEOSLOPE is a finite element program developed to analyze a wide spectrum of problems in Geotechnical, hydro-geological and mining engineering projects, has been used in the analyses.

Dynamic boundary conditions.

For a dynamic 2D earthquake analysis it is often reasonable to assume that the ground motion will be the same for some lateral extent beyond the site of interest. To approximate this we can allow the left and right vertical boundaries to move freely in the horizontal direction. The vertical boundaries at the ends are however not free to move up and down because they are connected to the ground beyond the problem. They probably move up and down during the shaking but we do not know how much. If we move the end boundaries far enough away from the area of main interest, then preventing the end boundaries from moving vertically is likely reasonable . In a real case the end boundaries should likely be further away from the embankment but for illustrative purposes the extent is adequate. To simulate this, we need to change the boundary specifications at the ends of the mesh. The left and right vertical boundary conditions need to be changed so the nodes are free to move in the horizontal direction but are fixed in the vertical direction.

Convergence Study.

In the present study, QUAKE/W module of GEOSLOPE was used for the analysis of dynamic slope stability using finite element technique. Convergence study was carried out using QUAKE/W, in order to decide the number of elements. The slope shown in Fig. 1 below is considered for convergence study. The number of elements is increased from 115 to 4000 elements. The number of elements was so chosen that the aspect ratio in all the cases was equal to one. Infinite elements, used along the boundaries of a mesh, allow to define the behavior of problem well beyond the extents of the finite element mesh.

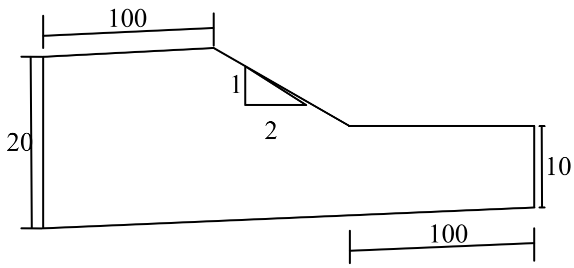

Fig. 1. Geometry of the Slope Considered for Convergence Study.

The assumed soil properties are; Unit weight (γ) 15 kN/m^3. Modulus of Elasticity (E): 20000 kPa, Poisson's ratio (μ): 0.40, Element type: 4 noded quadrilateral plane strain element. The Table1 shows the comparison of factor of safety study using GEOSLOPE which shows good agreement with the published work.

Table 1. Comparison of factor of safety values of GEOSLOPE with existing results

Description	Factor of safety
Day.R.W (2002)	0.734
Geo Slope results (Slope/W)	0.752

NEWMARK'S SLIDING BLOCK ANALYSIS

The sliding block theory was first presented by Newmark to estimate the permanent displacement of slopes on earth dams or embankments induced by earthquakes. The sliding soil mass was simplified by Newmark as a rigid plastic block. Lateral displacement of the block was expected to take place only when the ground acceleration exceeded the critical or yield acceleration of the soil mass. Once sliding commenced it was assumed to continue at a constant acceleration equal to the critical acceleration until the relative velocity between the sliding mass and the base became zero. For a given ground acceleration time history and a known critical acceleration of the sliding mass, the earthquake induced displacement is calculated by integrating those portions of the acceleration history that are above the critical acceleration and those portions that are below until the relative velocity between the sliding mass and the ground reduces to zero. According to this procedure, displacement takes place each time the ground acceleration exceeds the critical value.

PARAMETRIC STUDY

Dynamic loading is transient in nature and has frequency content, where as pseudo-static force acts constantly and is stationary. It is also true that pseudo static analysis gives higher factor of safety values than dynamic analysis and frequency effect is important for accurate slope stability analysis. Here an attempt is made to calculate the permanent displacement of slope under actual dynamic analysis considering various parameters. Dynamic stress analysis is carried out using QUAKE/W and permanent displacement of slope is carried out using SLOPE/W. For all the parametric studies, Uttarakashi earthquake motion is used as an input. The acceleration-time history is shown in Fig. 2.

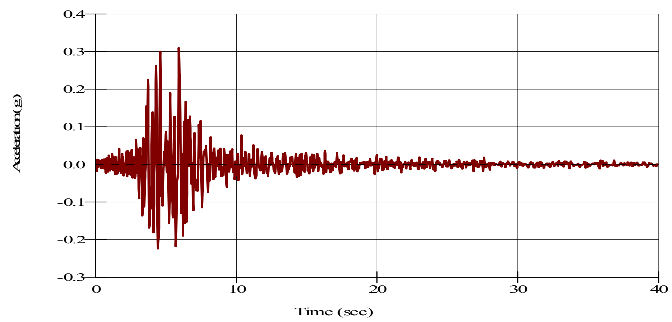

Fig. 2. Acceleration-time History of Uttarakashi Earthquake Motion

The salient characteristics of input motion in Uttarkashi region of Western Himalayas on October 20, 1991 at 02:53 hours are:

- Origin Time - 02:30:15.5 IST
- Epicenter - 30.74^{o}N, 78.79^{o}E
- Focal Depth - 19.0 km
- (30.73^{o}N 78.45^{o}E) component
- PGA 0.309g

The results are analyzed by plotting various graphs between variations of permanent displacement of slope along vertical axis with respect to different parameters like cohesion, inclination of slope and angle on internal friction of soil.

Effect of Cohesion of Soil

Cohesion is the important parameter, which affects the permanent displacement of slopes. An attempt is made to understand the effect of cohesion of soil on stability of slopes by varying cohesion from 0 to 160 kPa and keeping all parameters constant. It is found that there is significant reduction in the permanent displacement for a cohesion value from 0 to 60 kPa (Fig.3).

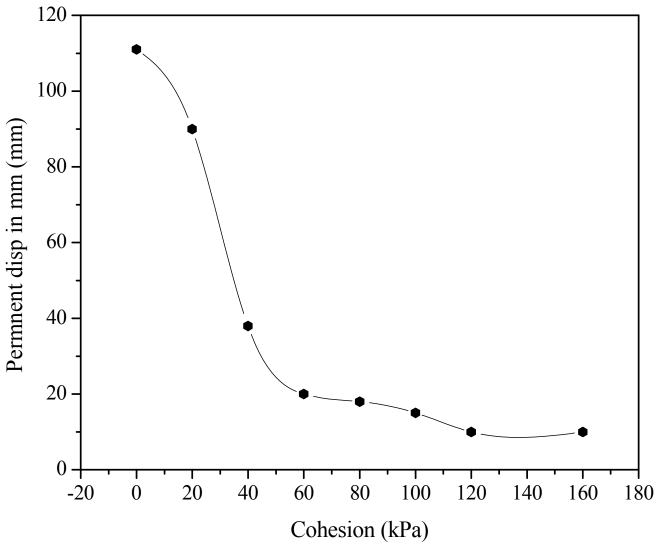

Fig. 3. Variation of permanent displacement with cohesion of soil

Effect of Angle of Slope

Permanent displacement is plotted along vertical axis and angle of slope is plotted along the horizontal axis. It is clearly observed that permanent displacement increase with increase in slope angle. The pattern of increase in permanent displacement is almost linear (Fig.4).

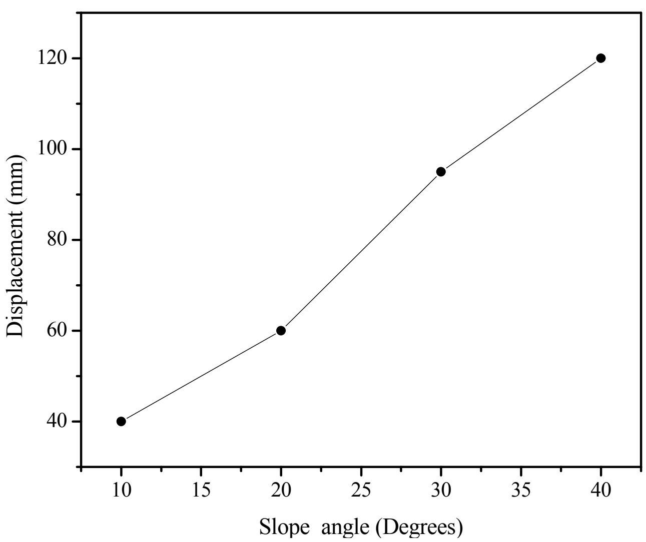

Fig. 4. Variation of permanent displacement with slope angle

Effect of Angle of Friction of Soil

Permanent displacement is plotted along vertical axis and angle of friction of soil is plotted along the horizontal axis. It is clearly observed that permanent displacement decreases with increase of angle of internal friction. It is found that there is significant reduction in the permanent displacement for values of angle of friction of soil from 0 to 20 degree (Fig.5).

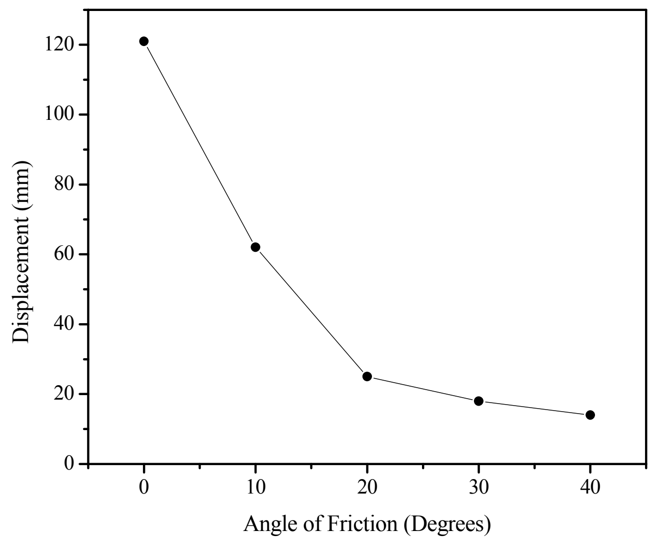

Fig. 5. Variation of permanent displacement with Friction angle

Peak crest Acceleration Response of the Embankment

The seismic acceleration response has been calculated & plotted for crest of the embankment. The considered values of cohesion and angle of friction of soil are 80kPa and 30^0 respectively. It is also found that the peak acceleration of crest is computed to be 2.5 to 3.0 times the PGA of input motion (Fig.6).

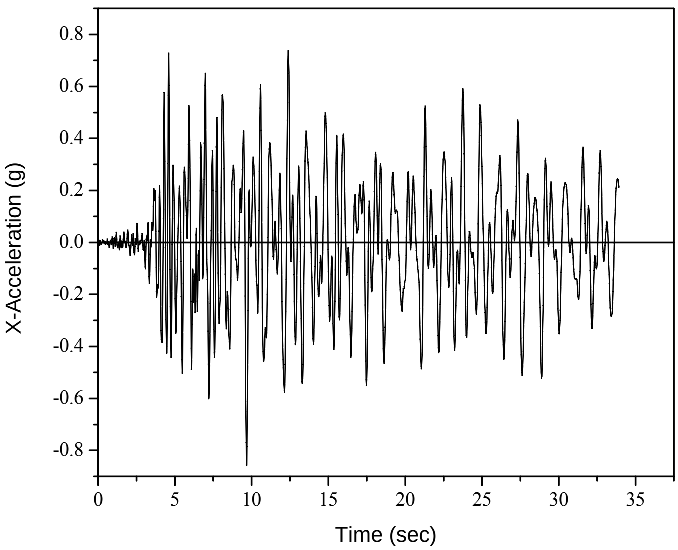

Fig. 6. Peak crest acceleration response of the embankment

CONCLUSIONS

The permanent displacement of earthen slope induced by earthquake motion are computed using finite element analysis. Newmark's approach has been used considering various factors such as geometry of slope, properties of soil in slope and earthquake motion. The study concludes as following:

- Permanent displacement decreases with increase in the angle of internal friction but the decrease is quite appreciable upto 20 degrees.
- Permanent displacement decreases with increase in the cohesion of soil but the decrease is quite appreciable upto 60kPa.
- Permanent displacement increases almost linearly with increase in angle of slope.
- In the dynamic analysis, the stable slope in static condition became unstable.

Therefore, the seismic stability analyses of slopes and evaluation based on permanent displacement is important than the evaluation of factor of safety as in pseudo static analysis.

REFERENCES

Kramer, S.L. [1996]. "*Geotechnical Earthquake Engineering*", Prentice Hall, Englewood Cliffs, New Jersey.

Newmark, N. [1965]. "Effects of earthquakes on dams and embankments,", Geotechnique, Vol. 15, No. 2, pp. 139-160.

Day.R.W [2002]. "*Geotechnical Earthquake Engineering Hand Book*", McGraw-Hill, USA.

GEOSLOPE [1992]. "User's Manual", Geo-Slope Office, Geoslope Intl, Calgary, Alberta, Canada.

Makdisi, F.I. and Seed, H.B. [1978]. "Simplified procedure for estimating dam and embankment earthquake-induced deformations", *Journal of Geotechnical Engineering Division, ASCE*, Vol. 104, No. GT7, pp. 849-867.

Govardhan, G. [2007]. "Construction of Design Response spectrum for Earthen Embankments", M.tech Thesis, SJCE Mysore, Karanataka